A Self-navigated Spiral In & Out Pulse Sequence Design for Retrospective Motion Correction

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Introduction Correction of motion artifacts still remains to be one of the most essential topics in MR. Especially in the case of uncooperative patients such as children and patients suffering from a medical condition that prevents them from staying stationary, accurate determination and correction of motion becomes a must for good image quality. In this study, we propose a spin-echo spiral in & out sequence for retrospective motion correction that is aimed to remove motion related artifacts in the case of in-plane rigid body motion. The spiral in & out sequence designed for this study can be used to get low resolution navigator data for each interleaf with no extra penalty in scan time. The modified SENSE reconstruction procedure uses that navigator data to find the motion parameters and eliminates the effects of undersampling in *k*-space.

Materials and Methods A spin echo Archimedian spiral in & out pulse sequence is designed for this study according to the algorithm described in [1]. Due to the gradient system limitations, a spiral trajectory mostly starts off in slew rate limited region and switches to amplitude limited region after a certain time which is determined by the scan parameters. In the case of the spiral in & out trajectory used for this study, a spiral in trajectory is used to get a fully sampled low resolution image for each interleave, and the spiral out part constitutes one of the interleaves of the final high resolution image (Figure 1). One advantage of this pulse sequence is that the spiral in portion makes use of the dead time after the 180^o degree pulse up to the echo time TE when the spin echo is formed. This introduces no penalty for scan time in case of T2 weighting and only slightly prolongs the minimum echo time for T1-weighting (TEmin = 20ms). This sequence has been tested on two normal volunteers using a 1.5T scanner (GE Signa LX, 11.0) with a high performance gradient system (Gmax = 50mT/m, SR = 150 mT/m/s) and an 8 channel head array (MRI Devices). The volunteers were asked to move their head inside the head coil by approximately 10-20 degrees for every 10 seconds during the scan to simulate in-plane rigid body motion. All human studies were approved by the review board of our institution. Other parameters used for the pulse sequence are as follows: TR/TE = 4000/56 ms, slice thickness/gap = 5/0 mm, 12 slices, FOV = 24 cm, matrix size = 256, interleaves = 32, NEX = 1, navigator matrix size = 32 and BW = 125 kHz. The data obtained from the scans were fed into a motion correction algorithm that uses the navigator images to accomplish co-registration and to obtain the amount of rotation and translation. After the determination of motion parameters, *k*-space trajectory, *k*-space data and the coil sensitivities are corrected accordingly by counter-rotating the *k*-space trajectories and applying a linear phase to *k*-space data. This motion correction introduces some gaps in *k*-space and causes aliasing in image domain. A modified version of the generalized SENSE algorithm that has a channel for each coil and for each interleave is used to remove aliasing and reconstruct the image. A detailed description of the correction algorithm can be found elsewhere in this volume.

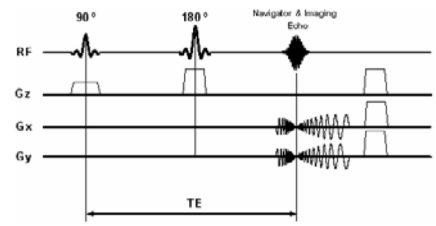

Figure 1*: The Spiral In & Out Pulse Sequence showing one interleaf of the image acquisition. The spiral in part is used to obtain a fully sampled low resolution navigator image for each interleaf and the spiral out part makes up one interleaf of the final high resolution image.*

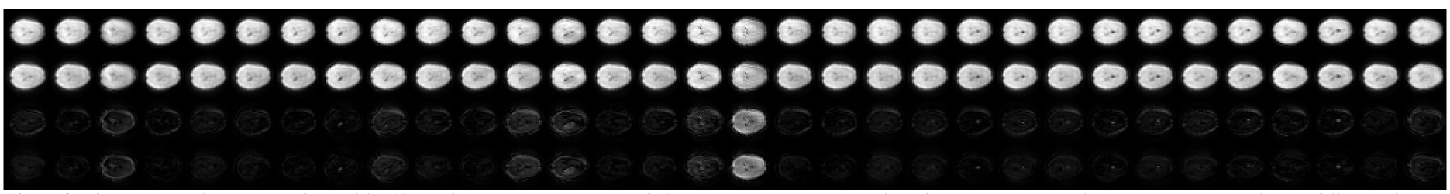

Figure 2*: The navigator data images obtained for 32 interleaves. Navigator images before registration (top row), aligned navigator images after registration (second row,) difference between the averaged navigator image (template) and the individual navigator images before registration (third row) and after registration (bottom row) are shown. In the difference images prior to the correction the misalignment is seen best by the bright contours at the circumference of the head. After correction the difference images clearly show a reduction of the misregistration. Difference images that are overall bright mostly reflect spin history changes due to through-plane motion.*

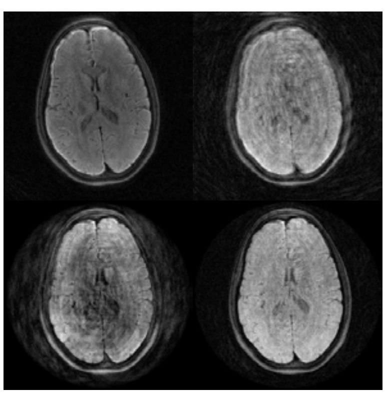

Figure 3 *– The results of motion correction in a subject with considerable head movement mimicking an uncooperative patient. A reference image without motion is shown on the top left side; top right: motion corrupted image without motion correction; bottom left: first iteration of the augmented SENSE reconstruction; bottom right: final motion corrected image after 10 iterations.*

Results The navigator images obtained for all 32 interleaves and the co-registered images are shown in Figure 2. Because of the motion, the subject is exposed to different combined coil sensitivity for each interleave. This results in navigator images having a slightly different intensity variation which might affect the registration. Coil sensitivity normalization – if available – might be advisable prior to registration. The results of motion correction are shown in Figure 3. The artifacts resulting from rigid body motion are significantly removed by the application of the motion correction algorithm. The modified SENSE algorithm provides improvement in the final image quality by filling in the gaps in k-space resulting from the counter-rotation of *k*-space trajectories. This is apparent from the difference between the initial image and final image in the SENSE iteration. An effective reduction factor, R_{eff}, is used as a measure of the *k*-space undersampling and is defined as the ratio of the maximum distance between two spiral arms to the original *k*-space sampling density. For the motion corrupted data sets given in Figure 2, R_{eff} is 1.65, which is a reasonable value that can be corrected with SENSE.

Conclusion The Spin-Echo Spiral In & Out Trajectory Design used in this study for motion correction significantly reduces artifacts resulting from in-plane rigid body motion. The pulse sequence efficiently utilizes otherwise unused time prior to the formation of a spin echo to acquire low resolution navigator images. In addition to motion detection these maps can simultaneously be used to generate coil sensitivity maps. Since we acquire the navigator information as an echo independent from the normal interleaf, the navigator does not affect the design of the imaging spiral part. With the given parameters, the readout time for each interleaf is around 15 ms, which justifies the assumption that motion occurs only between the interleaves and motion during the spiral readout is negligible. Although shown here for a spin echo approach, the spiral-in/spiral-out navigator pair can be also used for gradient echo imaging. Similar to T1w scans, the minimum TE is however slightly prolonged (+~5ms). This variant might potentially be useful for multi-shot fMRI or PWI studies. Future studies also include combining motion correction with phase correction in DTI studies.

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